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SALIVARY DIGESTION IN THE STOMACH.

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[FROM THE LABORATORY OF PHYSIOLOGY IN THE HARVARD MEDICAL SCHOOL.]

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SALIVARY DIGESTION IN THE STOMACH.¹

BY W. B. CANNON AND H. F. DAY.

[*From the Laboratory of Physiology in the Harvard Medical School.*]

IN stating the functions of saliva the common reference is to its importance as a lubricant in facilitating the movement of the parts of the mouth upon one another and in aiding the passage of the food through the œsophagus. There is a widespread impression that the chemical function is slight. Saliva can indeed change starch to sugar, but during mastication there is little time for amylolysis, and in the stomach the action of ptyalin is soon stopped by the acid gastric juice. Such is the view commonly expressed.² This paper is a report of a critical inquiry into the reasons for this view, and an experimental study of the degree of salivary digestion in the cardiac and pyloric ends of the stomach.

To support the conclusion that salivary digestion in the stomach is slight, certain studies of gastric contents after feeding starches are cited, and attention is called to the common conceptions of the effect of gastric peristalsis. Brücke³ found in the stomach contents of dogs killed one to five hours after eating starch paste or mush, no sugar or only slight amounts, unless it was already present in the food ingested. In 1877 v. Mering⁴ concluded, after feeding starch paste to dogs, that the saliva of dogs was without digestive influence, evidently because ptyalin was absent, and that in man, although ptyalin must be considered, it is of secondary importance. Observations on human beings by Ewald and Boas⁵ in 1886 seemed to

¹ A preliminary report of this research was presented to the American Physiological Society in December, 1902, and was printed in the proceedings of the meeting, *This journal*, 1903, viii, p. xxviii.

² See, for example, NEUMEISTER, *Lehrbuch der physiologischen Chemie*, Jena, 1897, pp. 287, 288.

³ BRÜCKE: *Sitzungsberichte der kaiserlichen Akademie der Wissenschaften*, Wien, 1872, lxxv, p. 144.

⁴ v. MERING: *Archiv für Physiologie*, 1877, p. 393.

⁵ EWALD and BOAS: *Archiv für pathologische Anatomie und Physiologie, und für klinische Medizin*, 1886, civ, p. 296.

sustain v. Mering's contention, for after giving patients starch paste to drink only slight amounts of sugar were found in the stomach. The next year Seegen¹ reported experiments in which he fed dogs carbohydrate food of diverse forms (flour cakes, potatoes, rice), and yet in the gastric contents failed to find more than a trace of sugar.

These chemical experiments tending to prove that saliva has only slight action in the stomach were supported by observations and theories of the churning effect of gastric peristalsis. Beaumont's² well-known description of the movement of the bolus along the gastric walls, and Brinton's³ theory of peripheral and axial streaming of the food in the stomach offered reasons for believing that all the food is rapidly mixed with gastric juice and is thus in a short time made acid throughout. The duration of salivary digestion must therefore necessarily be brief.

The conclusion from the above evidence that salivary digestion in the stomach is slight is not above criticism. In the first place the experiments of Brücke, v. Mering, and Seegen were performed upon dogs. The absence of sugar from the stomach, noted by these observers after giving a carbohydrate meal, is amply explained, as v. Mering admitted, by the fact that the dog's saliva does not possess a diastatic ferment.⁴ Even with ptyalin present in the saliva, which was the case in the experiments of Ewald and Boas on human beings, the starch paste as a test food would be objectionable. It is not only not palatable, but is in a state to be swallowed immediately without being chewed. There are thus two reasons for its not being mixed with sufficient saliva to cause noteworthy amyolysis. Inasmuch as there was no ptyalin, or almost no ptyalin, mixed with the food given in all these experiments, it is clear that they do not furnish direct evidence that salivary digestion in the stomach must be slight.

The indirect evidence against gastric amyolysis derived from Beaumont's observations and Brinton's reasoning as to mixing currents, is also subject to criticism. In 1898, Cannon⁵ brought forward proof that neither Beaumont's nor Brinton's account of the movement of the food in the stomach was correct. A marked difference was observed between the effects of the mechanical activities of the pyloric

¹ SEEGEN: *Archiv für die gesammte Physiologie*, 1887, xl, p. 46.

² BEAUMONT: *Physiology of digestion*, Plattsburgh, 1833, p. 110.

³ BRINTON: *The diseases of the stomach*, Philadelphia, 1865, p. 24.

⁴ See GRÜTZNER: *Archiv für die gesammte Physiologie*, 1876, xii, p. 285.

⁵ CANNON: *This journal*, 1898, i, p. 378.

and the cardiac portions of the stomach. In the cardiac portion there is no peristalsis, and the food, held in the tonic grasp of the gastric musculature, shows no signs of movement; in the pyloric portion, on the other hand, gastric peristalsis mixes the food thoroughly with the digestive juices. Little pellets of starch paste lying in the cardiac end immediately after the food is ingested may be seen with the X-rays in the same relative positions for almost two hours; the pellets in the pyloric end are moved to and fro by the passing waves of constriction. There is moreover a marked difference in the appearance of the contents of the two parts of the stomach after digestion has proceeded for even thirty minutes: the food in the pyloric end is usually far advanced toward chymification; the food in the cardiac end has still its original appearance, which it may retain even an hour and a half after ingestion. This observation that the food in the cardiac end of the stomach is not moved, and therefore is not mixed with the gastric juice, suggested that the cardiac contents might retain their original chemical reaction for a considerable period. Tests made on several cats and dogs, from one to one and a half hours after feeding, showed that the contents of the pyloric end were invariably strongly acid; the surface of the cardiac contents was also acid, but the internal mass in the cardiac end remained unchanged in its reaction. Inasmuch as salivary digestion may continue so long as free acid is absent, the conclusion was drawn that salivary digestion might proceed in the fundus for an hour and a half or longer without interference by the acid gastric juice.

The observations and the conclusion just detailed have been confirmed by Oehl,¹ and still more completely by Heyde working under Grützner² in Tübingen. Rats, rabbits, guinea pigs, and cats were fed by Heyde with different kinds of food in definite amounts and killed at different intervals after eating. The stomachs were carefully removed and frozen; sections were made through the frozen gastric contents, and acid indicators mixed with the food revealed at once the extent of acidification. The inner layers of the food in the cardiac end retained for hours a neutral or weakly alkaline reaction. Only the outer layers were slightly acidified and digested. Thus the diastatic ferment of the saliva may continue its action in the fundus for a long period wholly unhindered.

The difference in motor activities between the cardiac and pyloric

¹ OEHL: Archives italiennes de biologie, 1899, xxxii, p. 114.

² GRÜTZNER: Reprint from Deutsche Medizinal-Zeitung, 1902, No. 28.

ends of the stomach has been noted also in human beings. Beaumont's observations on Alexis St. Martin hint at a difference, and v. Pfungen¹ and Moritz² have made it certain that in man the peristalsis is confined to the pyloric end. Since Beaumont's time few observations have been made on the movements of the food in the human stomach. In 1897, however, Hemmeter³ stated that after many experiments on animals and investigations through fistulæ into the human stomach, he found no confirmation of Beaumont's and Brinton's views as to mixing currents. In 1900 Hemmeter⁴ repeated this statement and affirmed that Cannon's assertion that the food is churned by peristaltic waves only in the pyloric portion was correct. After thus bringing confirmatory data to prove the fundus free from peristalsis and after entirely rejecting the idea of mixing currents, he still declares that the contents of the fundus are soon mixed with the gastric secretions. The only explanation offered for this conclusion is that food taken from the stomach by means of an Einhorn bucket always contains gastric juice. Since the dorsal wall of the stomach in man slopes forward from the cardiac opening, a tube introduced through the œsophagus comes immediately in contact with the dorsal wall, and will remove first the food lying in proximity to the secreting mucous membrane. Clearly this faulty evidence allows no conclusion to be drawn as to the presence of acid in the interior of the cardiac mass, and such evidence cannot be accepted as contradicting the accumulated testimony, from much more exact methods, that the internal food in the fundus long remains unmixed with acid.

The discussion thus far has led to two conclusions: (1) that the reasons commonly given to prove salivary digestion possible in the stomach for only a short time are by no means convincing, and (2) that in the fundus, a reservoir in which the food may rest for hours unmoved, salivary digestion may indeed continue for a long period without interruption.

Several researches not widely quoted lend support to the view that salivary digestion in the stomach may be of importance. As long ago as 1880, von den Velden⁵ pointed out that free hydrochloric acid did not appear for almost an hour after eating breakfast and for almost two

¹ V. PFUNGEN: *Centralblatt für Physiologie*, 1887, i, p. 220.

² MORITZ: *Zeitschrift für Biologie*, 1895, xxxii, p. 339.

³ HEMMETER: *Diseases of the stomach*, Philadelphia, 1897, p. 86.

⁴ HEMMETER: *Loc. cit.*, second edition, 1900, pp. 85 and 88.

⁵ V. D. VELDEN: *Deutsches Archiv für klinische Medicin*, 1880, xxv, pp. 105 and 111.

hours after eating a full mid-day meal. Austen¹ in 1899, after studying one of his students, stated that for a period of at least one hour after an ordinary meal the albuminous matter of the food united with the hydrochloric acid of the gastric juice as fast as the acid was secreted and thus prevented it from stopping the digestion of starch. Hensay² and Müller³ were the first to present quantitative measurements of the amounts of sugar and dextrins which might be formed in the stomach when food is carefully chewed. These observers fed rice mush made pleasing to the taste with meat extract and butter. After a certain time, usually one half hour, they pressed out the gastric contents as completely as possible and secured the remnant by washing. They found that a large part of the expressed carbohydrates, 59.4 to 79.6 per cent, had been made soluble by the saliva. Of the dissolved carbohydrates over one half, even two thirds, consisted of maltose and of dextrins closely related to maltose, and the remainder of dextrins more nearly related to starch.

The four reports just mentioned combine to show that the common teaching that saliva must be unimportant in the stomach, because its action is quickly stopped, is not correct. Saliva certainly may be important in the digestion of starch if the food is well chewed and thus thoroughly mixed with the ferment. The observers who have brought forward these positive results have not, it will be noted, regarded the differences between the pyloric part of the stomach and the fundus. It was the purpose of the research here reported to study the conditions of salivary digestion particularly in the two portions of the stomach: in the active pyloric portion where the food is soon mixed with the acid juice; and in the quiet cardiac reservoir where the food lies unmoved for a long time until it begins to be forced gradually into the churning mechanism at the pyloric end.

METHOD.

The cat was the animal used in this investigation. The stomach of the cat, as observations with the X-rays have proved,⁴ is like the

¹ AUSTEN: Boston medical and surgical journal, 1899, cxl, p. 325.

² HENSAY: Münchener medicinische Wochenschrift, 1901, xlviii p. 1208.

³ MÜLLER: Sitzungsberichte der physikalisch-medicinische Gesellschaft, Würzburg, 1901, p. 4.

⁴ CANNON: This journal, 1903, viii, p. xxii; ROUX and BALTHAZARD: Archives de physiologie, 1898, xxx, p. 85; WILLIAMS: The Röntgen ray in medicine and surgery, New York, 1901, pp. 360-372.

stomach of the dog, rat, rabbit, guinea pig, and man, in being separable into two parts, — the quiet cardiac end and the active pyloric end. Moreover the mucosa of the cat's stomach resembles that of the dog and of man, not only in structure but also in pouring out an active secretion from almost every part of its surface.¹ The cat may be regarded, therefore, as a fairly typical animal for the purposes of the present investigation.

From twenty-four to thirty-six hours previous to an experiment the cat was allowed to fast, in order that the stomach might be free from food and prepared to receive the test meal. Crackers, examined and found free from sugar, were used as the test food. Unless otherwise stated a uniform amount of coarsely powdered crackers, 30 gms., was mixed with a uniform amount of filtered human saliva, 100 c.c. The mixture has a consistency of thick mush, similar to that of food chewed to a degree suitable for swallowing. The food thus prepared was given in one of two ways: it was either mixed in small amounts and fed immediately to the animal, or the total amount of crackers was mixed with the total amount of saliva and introduced at once into the stomach by a stomach tube. As the results were the same with both methods, the latter, because more expeditious, was usually employed.

After the food was in the stomach the animals were allowed to live one half hour, one hour, one and a half hours, or two hours. At the end of the time the animal was quickly etherized, the abdomen opened along the middle line and along a line toward the left parallel with the greater curvature of the stomach. With a curved hook a ligature was passed around the stomach at the region where the peristaltic waves start toward the pylorus,² and tied firmly. Thus the contents of the cardiac and pyloric portions were separated. The pylorus and cardia were next ligatured and the stomach removed with as little handling as possible.

Openings were now cut in the stomach wall and the contents of each part were emptied into an evaporating dish. The food in the pyloric end invariably had a consistency of thin mush. Occasionally hair or remnants of meat were found in the pyloric end; cases in which these disturbing factors were present have been excluded from this report.

¹ OPPEL : *Lehrbuch der vergleichenden mikroskopischen Anatomie der Wirbelthiere*, erster Theil, *Der Magen*, Jena, 1896, pp. 408, 443, 463; CARVALLO : Article "Estomac," *Dictionnaire de physiologie*, edited by Richet, Paris, 1902, v, p. 818.

² CANNON : This journal, 1898, i, p. 364.

The consistency of the food in the cardiac end was very different from that of the food in the pyloric end. It was not fluid, like the food in the pyloric end, and it often retained its shape sufficiently to permit the surface food to be separated from the internal mass.

The contents in the evaporating dishes, if not fluid, were slightly diluted with water, and the enzyme action quickly stopped by heating to the boiling point. The food was now evaporated to dryness by steam heat; the dry residue was ground to a fine powder in a mortar and kept in a desiccator until its weight was constant. One gram, removed from each part of the dried and powdered stomach contents, was mixed with 100 c.c. distilled water. After standing for about one half hour the mixture was filtered, and the filtrate was poured several times through the residue on the filter. In each instance 25 c.c. of the filtrate were taken for the sugar test. The sugar content, determined according to Allihn's method,¹ was estimated as maltose.² It was thus possible to know the percentage of sugar in the dry residue of the stomach contents.

FACTORS TO BE CONSIDERED.

The first and most important of the factors to be considered is the presence of free hydrochloric acid. As already stated, experiments in 1898 proved that free acid was absent from the middle of the cardiac mass for one and a half or two hours after eating. Similar tests made during the present research have confirmed the earlier observations. At the end of one half hour after a carbohydrate meal, free hydrochloric acid is present in the pyloric end of the stomach, but at the end of two hours there is no free acid present in the middle of the cardiac food.

Another factor to be regarded is the rapidity of salivary digestion. The common statements as to the speed of the change from starch into sugar are based upon observations on starch paste.³ Tests with other forms of starchy food show in some cases a much slower rate.⁴ Observations made on the test material used in this research, under-

¹ ALLIHN : *Zeitschrift für analytische Chemie*, 1883, xxii, p. 448.

² MUSCULUS and v. MERING : *Zeitschrift für physiologische Chemie*, 1878-9, ii, p. 409; EWALD and BOAS : *Loc. cit.*, p. 297.

³ CHITTENDEN and ELY : *Journal of physiology*, 1882, iii, p. 327.

⁴ HAMMARSTEN : *Jahresberichte über die Fortschritte der Thierchemie*, 1871, i, p. 187.

going salivary digestion *in vitro* at 38° C., show that in seven minutes four fifths of the amount of sugar found at the end of an hour is already present. To be sure, under these conditions the accumulation of the products of the digestion inhibits the rapidity of the action of the ferment as time passes,¹ but it is clear that salivary digestion is sufficiently rapid to cause a considerable amylolysis before the acid is secreted even in the pyloric end to a degree preventing further activity of the ptyalin.

Control experiments were made to discover if in the stomach or in the treatment of its contents there was any factor which, aside from the saliva, would result in any considerable change from starch to sugar. Crackers mixed with distilled water were fed to animals, and after an hour the stomach contents were treated in the usual routine. Under these conditions only the slightest traces of a reducing agent were discovered.

RESULTS.

The difference in salivary digestion in the two ends of the stomach after different periods of time is shown in the table on page 404.

Several matters are to be noted in reference to the figures in this table. There is a remarkable diversity in the amount of maltose present in different cases having the same period of digestion, and there is no very uniform increase in the figures as the period of digestion is prolonged. Probably numerous agents are concerned in producing this diversity, but control experiments carried on *in vitro* indicate that the most important cause is the variation in the activity of the saliva at different times, — a fact to which attention has been called by several observers.² It is evident that the figures in these cases cannot be compared absolutely; in each instance, however, the ratio of the change in the two parts of the stomach may be taken and these ratios will serve for comparisons.

The ratios derived from the figures show that there is in every case a greater percentage of sugar present in the cardiac end than in the pyloric end. Two considerations serve to prove that the actual differences between the *total amounts* of sugar produced in the two ends of the stomach are notably greater than the differences between

¹ LEA: Journal of physiology, 1890, xi, p. 239.

² See HOFBAUER: Archiv für die gesammte Physiologie, 1897, lxxv, p. 503; CHITTENDEN and RICHARDS: This journal, 1898, i, p. 461; OEHL: Memorie del reale istituto lombardo di scienze e lettere, 1902, xix, p. 135.

the sugar present in unit volumes of the dried contents. In the first place, as previously stated, the pyloric contents are invariably more fluid than the cardiac contents: it follows, therefore, that, since a

In this and in subsequent tables each number represents the fractional gram of maltose present in one gram of dried contents of different parts of the stomach, after different periods of time.

Period.	Date.	Pyloric end.	Cardiac end.	Ratio.
$\frac{1}{2}$ hr.	July 15	0.352	0.363	10 : 10.3
	Aug. 1	0.171	0.209	10 : 12.2
	Jan. 14	0.338	0.401	10 : 11.9
	Average ratio			10 : 11.5
1 hr.	July 18	0.293	0.472	10 : 16.1
	Aug. 1	0.095	0.174	10 : 18.3
	Jan. 30	0.111	0.206	10 : 18.5
	Average ratio			10 : 17.6
$1\frac{1}{2}$ hrs.	July 11	0.360	0.506	10 : 14.0
	" 18	0.244	0.384	10 : 15.7
	" 26	0.262	0.295	10 : 11.2
	Aug. 1	0.135	0.244	10 : 18.0
	Jan. 14	0.291	0.360	10 : 12.3
	Average ratio			10 : 14.2
2 hrs.	July 15	0.315	0.455	10 : 14.4
	" 26	0.291	0.322	10 : 11.0
Average ratio				10 : 12.7

larger amount of fluid must be evaporated from the pyloric food than from the cardiac food, in order to secure the dried masses, there is relatively less sugar in a unit volume of the original pyloric food in

comparison with a unit volume of the original cardiac contents than the ratios given in the tables would indicate. For this reason, therefore, the actual disparity of sugar production in the two ends of the stomach is greater than that seen in the dried contents. The second factor increasing these differences is the inequality in the cubic contents of the two ends of the stomach. After a full meal the cardiac end holds by far the greater part of the food. Several observations on the relative capacity of pyloric and cardiac portions of the stomach, as shown by their contents after the ingestion of about 100 c.c. of food, brought forth the average ratio of 1 to 5. In order to get the ratio of the total amounts of sugar in the two regions it is necessary to multiply the cardiac figure by 5; from this factor alone, therefore, the ratios given in the above table change so that they are as 10 to 57.5 for one half hour, as 10 to 88 for one hour, as 10 to 71 for one and one half hours, and as 10 to 63.5 for two hours.

It is to be observed that after one half hour the amount of sugar in equal parts of the dried contents of the two regions of the stomach is almost the same, that the greatest difference between the two regions appears in the estimates for one hour, and that the ratios for an hour and a half and for two hours again approach unity. Without much doubt the reason for the percentage sugar content being almost the same in the two portions of the stomach at the end of a half hour is that within that time the sugar formation takes place at almost equal rates in the two portions, *i. e.*, for some time after the ingestion of food the ptyalin is not inhibited even in the pyloric region by the appearance of free acid. Every examination of cases in which digestion had proceeded for a half hour demonstrated that free acid was already present in the pyloric contents. Salivary digestion in the pyloric end of the stomach was therefore at a standstill. That salivary digestion does not cease, however, in the pyloric end until toward the end of the half hour is shown by the large amount of sugar produced compared with that in the cardiac end. On the other hand, the fact that there is a difference between the sugar percentages in the two portions shows that the free acid in the pyloric end has had an inhibitory effect. This inhibitory effect is more marked if the speed of action of the ptyalin is retarded (as, for example, by diluting it), for then the acid has opportunity to check the activity before considerable change has occurred. Thus in the stomach of an animal fed 30 gms. crackers mixed with 100 c.c. diluted saliva (saliva 25 c.c., water 75 c.c.), the ratio of sugar percentages at the end of a half hour was

not near 10: 11.5, the average when undiluted saliva was given, but was as 10 to 20, a ratio approximating that found at the end of an hour when undiluted saliva is used. Under ordinary circumstances in human beings the saliva is thus diluted by drinking at meals. If the results secured with the cat may be transferred to the human subject (a matter to be considered later), the factor of dilution would certainly enhance the relative value of the fundus as a region for salivary digestion.

The change in the ratios in the above tables, from 10 : 17.6 at the end of an hour, to 10 : 12.7 at the end of two hours, can be considered only after evidence of other changes has been presented. The evidence for these changes will now be given.

It is certain that the sugar formed is in solution, and it is highly probable that this solution may diffuse from a region in which it is more concentrated into a region in which it is less concentrated. It may also pass to the lowest position which a fluid may take in the stomach. That such changes in the sugar concentrations in the stomach occur is evidenced by the following observations. In four animals digestion was allowed to proceed for one and a half hours. The contents of the cardiac end were then removed in two parts: an external mass from near the ventral wall of the stomach, which was lowest during digestion; and the internal mass, dorsal in its relation to the first mass. When these masses were dried the sugar percentages were as follows:

Date.	External food (from lowest part).	Internal food (from higher part).
July 11	0.511	0.500
" 18	0.410	0.357
" 26	0.326	0.263
Jan. 14	0.360	0.281

These results indicate that as the sugar solution is formed it passes into a dependent portion of the stomach. Further data on this point were secured by having an animal rest on the left side during a digestive period of an hour. Since the cat's stomach lies more nearly transverse than longitudinal in the body, the position on the left side caused the cardiac end to lie below the pyloric. The sugar

percentages of the food in the most dependent portion and in the interior are as follows:

Date.	External food (from lowest part).	Internal food (from higher part).
Aug. 4	0.398	0.301
Dec. 15	0.482	0.468
Jan. 15	0.481	0.422

When an animal lies on its *right* side during an hour of digestion, opposite results are secured from the cardiac end, thus:

Date.	External food (from highest part).	Internal food (from lower part).
Jan. 14	0.291	0.423

As already noted, at the end of an hour or an hour and a half the food near the wall in the cardiac end of the stomach almost invariably shows the presence of free acid, while the internal food of this region retains its original reaction. Evidently in the cases cited the internal region, favorable for amyolysis, contains less sugar than the dependent region, in which the process is hindered or prevented. The most reasonable explanation for a larger amount of sugar near the dependent gastric wall than in the interior of the food mass, is that the sugar solution runs into the lowest region from the effect of gravity.

Inasmuch as the sugar solution passes thus from the midst of the food in the stomach to the gastric wall, it is probable that diffusion also occurs from the cardiac region into the pyloric region, in which sugar is present in less amount. The fact of diffusion can readily be demonstrated by feeding first meat, and later starchy food mixed with saliva. Under such circumstances the meat is found crowded against the greater curvature, the starchy food lies along the lesser curvature, and between the two foods a perfectly clear separation is possible. If the meat by itself causes no reduction of copper, whatever reduction it may cause subsequent to its being in the stomach alongside of food undergoing amyolysis must be due to diffusion of sugar

into the meat. An animal was fed thus with shredded canned salmon and later with crackers mixed with saliva; and the meat taken at the end of an hour from near the surface in the cardiac region, fully a centimetre and a half from the starchy food, although originally giving no reaction for sugar, contained about 0.7 per cent sugar calculated as maltose. Since the sugar in the starchy food was only 27 per cent, the relative per cent of sugar in the meat was almost 3 per cent. Diffusion of sugar into the meat had evidently taken place to a considerable degree.

A further result of the solution of the sugar is the possibility, in this state, of its being absorbed. Brandl¹ and v. Mering² have proved that sugars may be absorbed from the stomach, and have shown that within limits the rate of absorption increases with the increase of concentration of the solution. Inasmuch as the sugar is present in the cases under consideration in somewhat high concentrations, it is certainly very likely that some sugar is absorbed directly from the stomach.

Only these facts of diffusion and absorption will explain certain observations repeatedly made in the course of the experiments, namely, that control digestions *in vitro* almost invariably resulted in the production of more sugar than could be found in the cardiac end of the stomach. Typical examples of the difference are as follows:

Date.	Control food (<i>in vitro</i>).	Cardiac food.
July 18	0.473	0.384
“ 26	0.309	0.295
“ 11	0.436	0.506
Aug. 1	0.309	0.244

In these instances there is no free acid present in the cardiac end to prevent the action of the ptyalin; and, moreover, the action of the ptyalin is not retarded by its products, for there is not so great an accumulation of sugar in the fundus as in the control dishes. The

¹ BRANDL: Zeitschrift für Biologie, 1892, xxix, p. 277.

² V. MERING: Verhandlungen des xii Congresses für innere Medicin zu Wiesbaden, 1893, p. 471.

facts already presented justify the conclusion that there is a continuous formation of sugar in the fundus, that as the sugar is formed it diffuses from the region of greater concentration into regions of less concentration, and that it is absorbed as it comes in contact with the gastric walls. Thus the differences between sugar percentages in the two ends of the stomach would become less as time elapsed, and thus there might readily be less sugar present in the cardiac end of the stomach than in an artificial digestion from which the products do not pass away.

It is probable that as the sugar diffuses from the region of greater concentration into regions of less concentration a certain amount of the ptyalin is carried away with it. That this loss is not serious is shown by making a watery extract of the cardiac contents and testing its amylolytic power. Such extracts were made of pyloric contents, and of food near the surface and in the interior of the cardiac end after digestion had proceeded for an hour. Tested with starch paste, blue with iodine, these extracts gave the following results: pyloric food, no change of color in four hours; surface of cardiac food, slight change of color; interior of cardiac food, complete disappearance of color in a short time. Manifestly ptyalin was still active in the cardiac end of the stomach.

Further evidence of absorption was secured by feeding two animals with equal amounts of the same food mixed with equal amounts of the same saliva, and examining the stomach contents at different intervals after the food was given. The experiment was tried twice with the following results:

Date.	Period.	Cardiac food.	Pyloric food.
July 15 . . .	$\frac{1}{2}$ hours	0.363	0.352
	2 "	0.455	0.315
Aug. 1 . . .	$\frac{1}{2}$ "	0.209	0.171
	$1\frac{1}{2}$ "	0.244	0.135

In these two cases the cardiac sugar content increases as time goes on; naturally it would be expected that as the cardiac food passes into the pyloric end the pyloric sugar content also would increase; instead, however, as time goes on there is a decrease in the percentage in the pyloric end. These two cases are not sufficient to allow sure

conclusions to be drawn, but they indicate that sugar passes out of the pyloric end of the stomach more rapidly than the undissolved portions of the food. A selective action at the pylorus is hardly to be expected, for the food that comes to it is not a mixture of hard particles in fluid, but a uniform creamy substance. Active absorption at the pyloric end, for which the peristalsis is especially favorable, is suggested as an explanation of the results which these two cases furnish.

Effect of position on sugar formation.—It is important to know if position has an effect on the mixing of the gastric contents with the gastric secretions, and if thereby salivary digestion is modified. Observations were made on animals caused to rest on the right side or on the left side during the period of digestion. As the full stomach in the cat lies nearly transverse, the long axis of the organ was nearly vertical in either case. The results secured were as follows:

ANIMALS ON LEFT SIDE.			
Date.	Pyloric end.	Cardiac end.	Ratio.
Aug. 4 . . .	0.191	0.350	10 : 18.3
Dec. 15 . . .	0.435	0.475	10 : 10.9
Jan. 15 . . .	0.227	0.451	10 : 19.8
Average ratio 10 : 16.3			
ANIMALS ON RIGHT SIDE.			
Dec. 15 . . .	0.306	0.473	10 : 15.4
Jan. 14 . . .	0.251	0.357	10 : 14.2
Average ratio 10 : 14.8			

Examination of these results reveals no very marked differences in the ratios of sugar content when the long axis of the stomach is reversed in direction. If the animal is on the left side, with the cardiac end lower than the pyloric end, there is, however, more sugar present in the food in the fundus than is the case when the opposite relation of the parts is maintained.

Effect of variations in the food, and massage. — When the food is liquid, it is to be expected that the gastric juice will be more readily and more uniformly mixed with the food than when the food is present in somewhat viscid masses. Crackers (30 gms.) were ground to a coarse powder and mixed with 150 c.c. filtered saliva. The mixture was about as fluid as the chyme ordinarily seen in the pyloric end of the stomach. After one hour the percentage sugar content in dried food from the two ends of the stomach was as follows :

Date.	Pyloric end.	Cardiac end.	Ratio.
Dec. 15 . . .	0.427	0.519	10 : 12

The average ratio for one hour with the usual test food was 10 : 17.6; with the liquid diet there is a considerable decrease in the disparity.

Similarly small amounts of food in the stomach would naturally be more quickly and uniformly permeated by the gastric secretions, and the differences to be observed when large amounts are given would not under these circumstances be expected. Animals were fed one half the usual test meal, — 15 gms. crackers, 50 c.c. saliva, — and digestion allowed to proceed for one hour. The following results show the sugar production in the two parts of the stomach :

Date.	Pyloric end.	Cardiac end.	Ratio.
Aug. 4 . . .	0.369	0.349	10 : 9.4
Jan. 30 . . .	0.296	0.284	10 : 9.6
Average ratio 10 : 9.5			

In these cases more sugar is present in a unit weight of dried pyloric content than in a unit weight of dried cardiac content, a fact difficult of explanation.

A difference in the ratios similar to that observed when the amount of food was small was seen in two instances in which the upper abdomen was massaged at intervals of about five minutes during one

hour of digestion. The sugar content in these instances was as follows:

Date.	Pyloric end.	Cardiac end.	Ratio.
Aug. 4 . . .	0.484	0.391	10 : 8.1
Dec. 15 . . .	0.493	0.423	10 : 8.6
Average ratio . . . 10 : 8.4			

In these instances, as when liquid food or a small amount of food was given, the sugar content of the two ends of the stomach was more nearly the same than in the usual cases with large amounts of semi-solid food resting in the stomach undisturbed. The larger percentage of sugar in the pyloric end, when little food was given and when the stomach after a full meal was massaged, was not expected and cannot at present be explained.

Effect of combining proteid with carbohydrate food. — From the work of Pawlow and his school¹ it is to be expected that after the introduction of flesh food, the character of the secretion of the gastric juice will change; there will be in the early stages of digestion a more abundant flow of gastric juice, with a concomitant greater production of hydrochloric acid, than is normal when carbohydrates alone are ingested. On the other hand, as pointed out by Chittenden and Smith,² proteid not only favors the diastatic action of ptyalin by combining with hydrochloric acid so as to delay the appearance of the free acid, but also seems to act, in the form of a small percentage of acid proteid, as a direct stimulant to diastatic action. The effects of proteid favorable to diastatic activity might therefore counterbalance the extra production of acid destructive to that activity. Such in fact was the result of experiment. A cat was fed 45 gms. of thoroughly mixed fish and crackers (25 gms. salmon, 20 gms. crackers) and 100 c.c. diluted saliva (50 c.c. saliva, 50 c.c. water). After one hour the stomach was examined in the usual manner. No free acid was found in the cardiac end, and in the pyloric end there was only a slight

¹ PAWLOW: The work of the digestive glands, London, 1902, pp. 31, 34, and 35.

² CHITTENDEN and SMITH: Studies from the laboratory of physiological chemistry, Sheffield Scientific School of Yale College, 1885, i, p. 33.

discoloration of the test paper. The food, treated in the manner already described, yielded the following amounts of sugar:

Internal cardiac, 0.153

External cardiac, 0.152

Pyloric, 0.147

The ratio of sugar production in the two parts of the stomach when flesh is added to the carbohydrate food — about 10 to 10.3 — need only to be compared with the ratio obtained when carbohydrate food alone is given — 10 to 17.6 — to see that the proteid protects the ptyalin from the acid in the pyloric end and permits the diastatic action to continue for an hour at least at a rate equal to that in the cardiac end. It should be remarked that the protection afforded by the proteid is really effective only in the relatively small pyloric portion of the stomach and to some extent on the surface of the cardiac portion. The greater mass of the food, lying in the fundus, undergoes uninterrupted amylolysis, not because the proteid protects the ptyalin, but because the food in this region is not mixed with the gastric juice.

Change of starch into dextrin. — Starch not changed to maltose in the stomach may be changed in considerable degree to dextrin. Inasmuch as dextrin is not directly fermentable, the amount of dextrin thus produced represents just so much carbohydrate food preserved from possible loss to the organism by fermentation. The amount of dextrin formed was roughly calculated in several cases as follows. One gram of the dried stomach contents was taken, about 100 c.c. water were added, and after one half hour the mixture was filtered through a weighed filter, on which the residue (starch and proteid) was several times washed, then dried, and residue and filter together weighed again. The loss of weight was taken to represent the soluble carbohydrates. From the total weight of soluble carbohydrates was deducted the weight of the sugar, and the remainder indicated the dextrin formed. The salts present were not determined. The dextrin thus roughly estimated varied in several instances between seventeen and forty per cent. The following example illustrates the relations between the various products in the different parts of the stomach:

Aug. 1	Amount taken.	Starch.	Dissolved.	Maltose.	Dextrin.
Internal cardiac	1.0	0.354	0.646	0.250	0.396
External cardiac	1.0	0.441	0.559	0.237	0.322
Pyloric	1.0	0.687	0.313	0.135	0.178

In all cases there was a large amount of dextrin in the internal part of the cardiac contents, to which the hydrochloric acid penetrates last. Evidently fermentation may proceed for a long time in this region unchecked by acidity. It is of obvious advantage, therefore, to have in this region a considerable amount of the starch ingested preserved to the organism by being changed to a form fermentable with difficulty or not at all.

DISCUSSION OF RESULTS.

In reviewing the observations here recorded on salivary digestion in the cardiac and pyloric ends of the stomach it is to be observed that invariably under normal conditions, when ordinary amounts of food are given, more sugar is produced in the cardiac than in the pyloric end. The conditions present in the cardiac end of the stomach are wholly in agreement with the contentions of observers who have urged that saliva may continue its chemical function for some time after being swallowed; the conditions present in the pyloric end, however, are very different, for the food there soon becomes acid and the action of the saliva stops. In 1880 von den Velden divided gastric digestion into two periods; in the first period, before free hydrochloric acid appears, the saliva swallowed with the food is still effective; in the second period, after free hydrochloric acid appears, only the pepsin continues activity. It is clear, however, from the results presented, that these two periods are different in the two ends of the stomach; in the pyloric end the first period is short, in the cardiac end it may last three or four times longer than it lasts in the pyloric end. In the early stages of digestion in the stomach, therefore, the cardiac end serves chiefly for salivary digestion; the pyloric end, after a brief course of salivary digestion, is thenceforth the seat of the strictly peptic changes. Later, as the cardiac contents become penetrated by gastric juice, diastatic activity ceases, and the stomach contents as a whole are subjected to the action of proteolytic ferments.

It is of interest to note that the results reported in this paper are in close agreement with the results obtained by Ellenberger and Hofmeister¹ in their observations on the horse and pig, and by Hohmeier² in his observations on the rat. The cardiac end of the stomach in

¹ ELLENBERGER and HOFMEISTER: *Archiv für wissenschaftliche und praktische Thierheilkunde*, 1884, vii, p. 6, and 1886, xii, p. 126.

² HOHMEIER: *Inaugural-Dissertation*, Tübingen, 1901.

the horse, the pig, and the rat is to a great extent lined with pavement epithelium and with "cardia glands," distinguished from the fundus glands in not having an acid secretion.¹ According to these observers this region becomes, in the absence of gastric secretion, the seat of prolonged amylolysis. That there is this similarity in salivary digestion between animals without acid secretion in the cardiac end and animals with free secretion there, indicates that the division of the stomach into two regions with functions chemically different during the early stages of gastric digestion is a general fact. The important agent in either case is the mechanical agent — the absence of peristalsis in the cardiac end and the consequent quiescence of the food in this region. As already pointed out (p. 401), the distinction between the active pyloric and the inactive cardiac end of the stomach has already been observed in many animals including man. It is altogether probable, therefore, that in man as in other animals the cardiac end serves chiefly for the action of ptyalin during the early stages of gastric digestion.

The recent observations of Müller and of Hensay, together with the results here presented, emphasize strongly the importance of mastication. Only by mastication is the food properly mixed with saliva and properly broken up so that all parts of it can be penetrated readily by the saliva. When the food has thus been thoroughly insalivated it will undergo to a great degree salivary digestion in the cardiac end of the stomach.

SUMMARY.

The evidence that the action of ptyalin is inhibited in the stomach soon after the ingestion of food is inconclusive. The support for this evidence from the commonly accepted accounts of mixing currents in the stomach is not well founded. Observations show that in many animals, including man, gastric peristalsis occurs only in the pyloric end of the stomach; the cardiac end remains undisturbed by the waves. Food in the pyloric end is soon mixed with the gastric secretions, but food in the cardiac end of the stomach is not mixed with the acid gastric juices for two hours or more, and in this region, therefore, during that time salivary digestion may go on undisturbed.

Examination of the dried contents of the pyloric and cardiac portions of the stomachs of cats, after carbohydrate food mixed with

¹ OPPEL: *Lehrbuch der vergleichenden mikroskopischen Anatomie der Wirbelthiere, erster Theil, Der Magen*, Jena, 1896, pp. 240, 337, 346, 397.

active saliva has been given, shows that the percentage of sugar present is about the same in the two portions at the end of a half hour, and at the end of an hour the cardiac portion contains about eighty per cent more sugar in unit volumes than the pyloric portion. The actual amount of sugar present in the fundus is relatively much greater than this ratio would indicate, for the fundus contains after an ordinary meal about five times as much food as the pyloric portion.

After an hour the ratio of the sugar percentages in the two parts of the stomach begins to approximate unity again. This change is probably due largely to diffusion of sugar from the fundus into the pyloric end, and to some extent to absorption.

The diffusion of the sugar does not to a marked degree remove the ptyalin from the food.

Position does not very notably affect the differences in sugar production between the two parts of the stomach, although with the fundus lower than the pyloric portion slightly more sugar is found in the fundus than when the opposite relation is maintained.

When liquid food is given, when small amounts of food are given, and when the stomach is massaged, sugar percentages in the two parts of the stomach are nearly the same.

Mixing proteid with carbohydrate food protects the ptyalin from the action of free hydrochloric acid in the relatively small pyloric part of the stomach and on the surface of the cardiac contents. The greater mass of the food, lying in the fundus, undergoes uninterrupted amylolysis, not because the proteid protects the ptyalin, but because the food in this region is not mixed with the gastric juice.

Much of the starch not changed to sugar is changed to dextrin, and thus, since dextrin is not readily fermented, the food is saved to the organism. The especial value of this process lies in the fact that it occurs to the greatest degree in the fundus, in which region the hydrochloric acid, inhibiting the action of many of the organized ferments, does not for some time make its appearance.

In the early stages of gastric digestion, if food has been properly masticated, the fundus serves chiefly for the action of the ptyalin; the pyloric portion, after a brief stage of salivary digestion, is thereafter the seat of strictly peptic changes. Later, after two hours or more, as the contents of the fundus become acid, the food in the stomach as a whole is subjected to the action of proteolytic fermentation.

